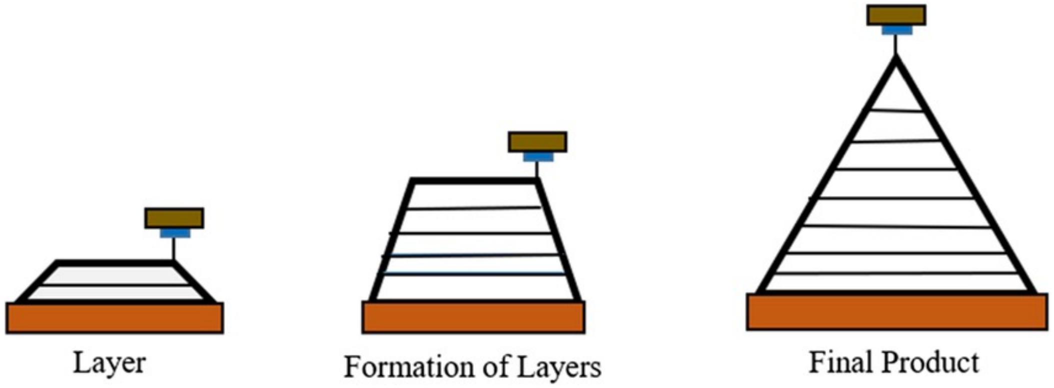
Additive Manufacturing Process

ME323 : Thermal and Chemical processing of materials
Instructor: Prof. Ramesh Singh

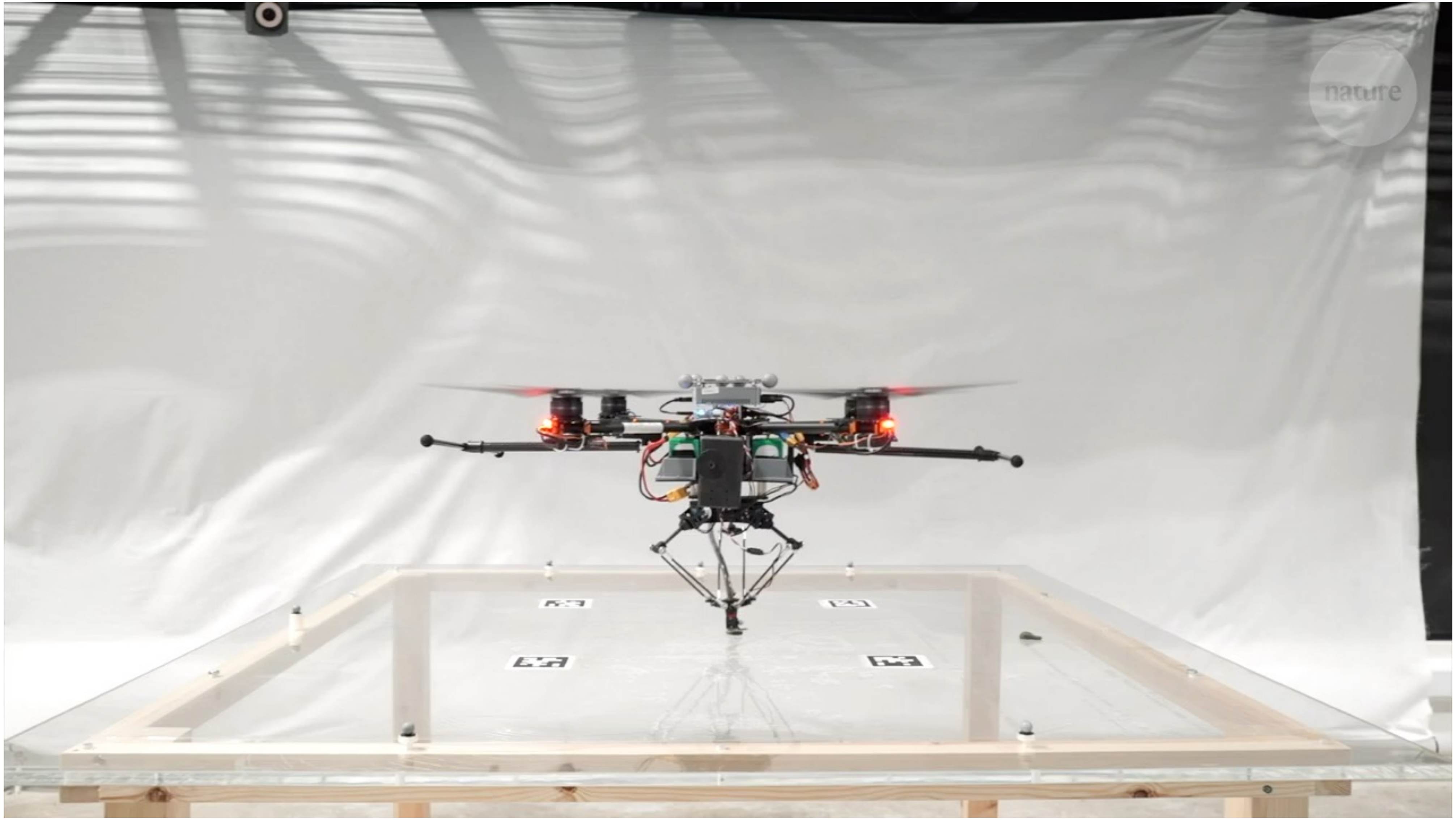
Introduction to Additive Manufacturing

- Definition: Layer-by-layer fabrication of objects.
- Also known as 3D Printing, Rapid Prototyping.
- Compared to Traditional Manufacturing:
  - Minimal material usage
  - No tooling required
  - High customization

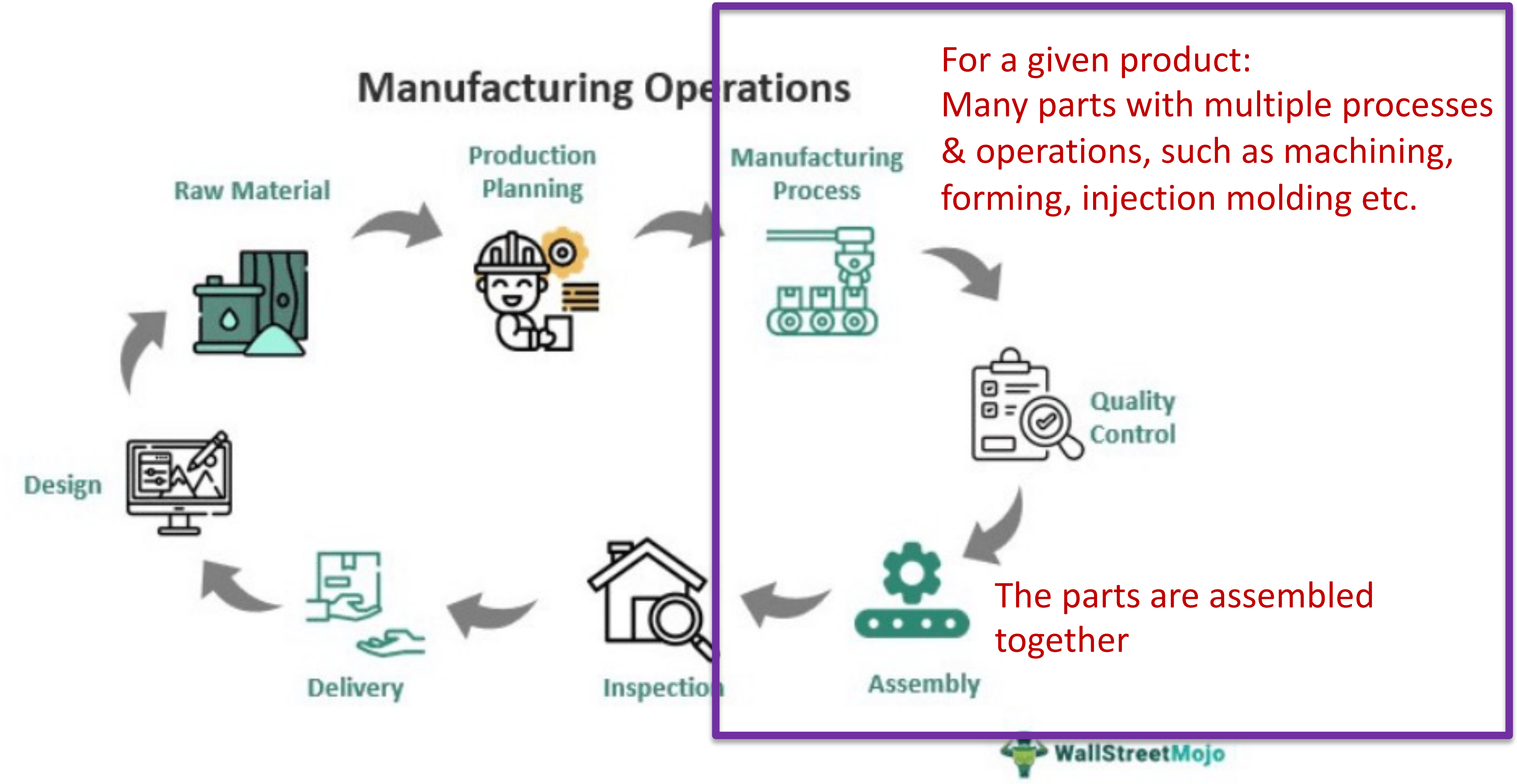


https://www.youtube.com/watch?v=pDKNEO0gDuE

3-D Printing by Drones



Conventional Manufacturing Versus AM

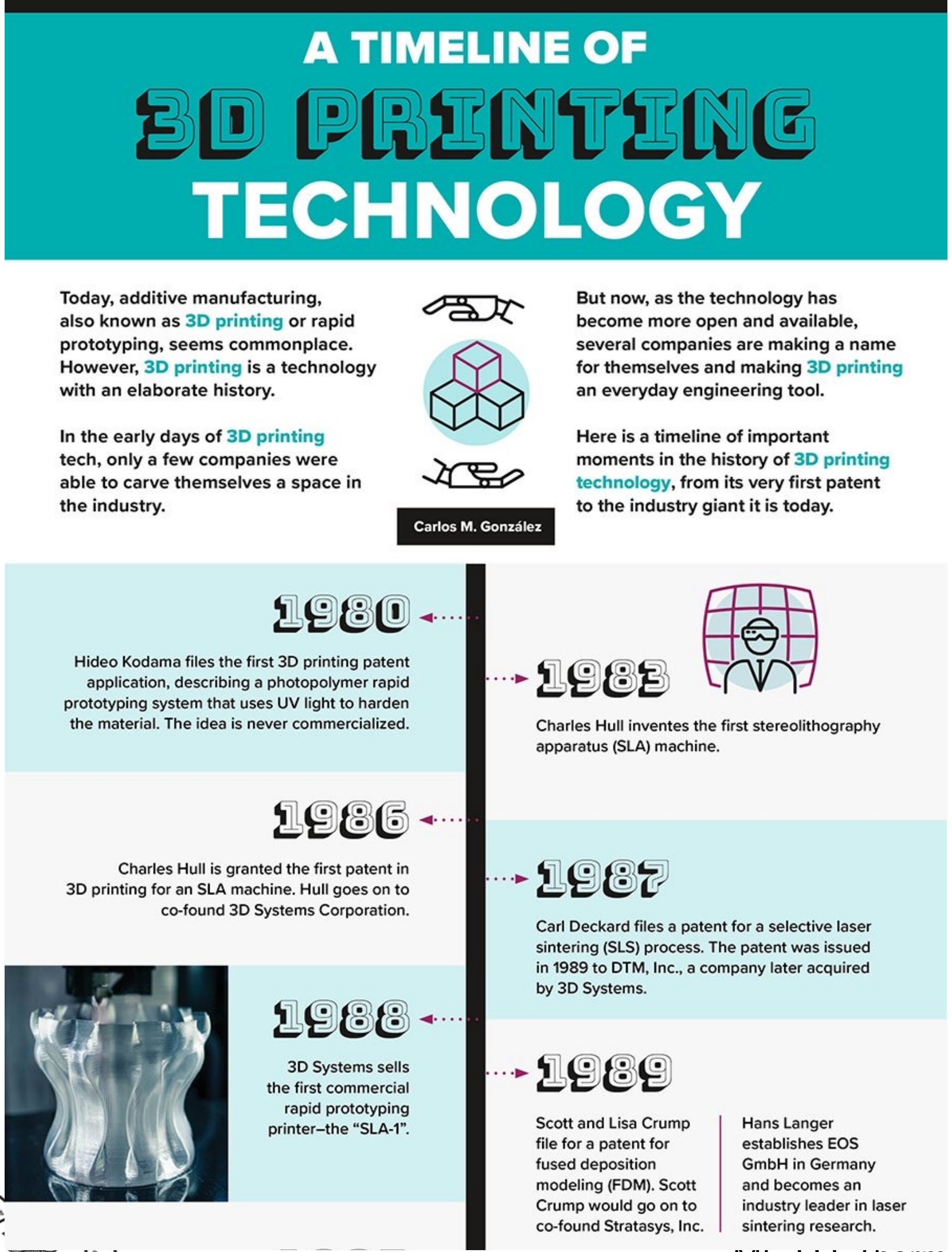


For a given product:
Many parts with multiple processes & operations, such as machining, forming, injection molding etc.

The parts are assembled together

AM has the potential to:

- Reduce the tooling requirement, such as molds/dies and cutting tools
- Assembly of multiple parts
- Reduced material wastage than machining
- High level of part complexity and internal features can be created



A TIMELINE OF 3D PRINTING TECHNOLOGY

Today, additive manufacturing, also known as **3D printing** or rapid prototyping, seems commonplace. However, **3D printing** is a technology with an elaborate history.

In the early days of **3D printing** tech, only a few companies were able to carve themselves a space in the industry.

Carlos M. González

But now, as the technology has become more open and available, several companies are making a name for themselves and making **3D printing** an everyday engineering tool.

Here is a timeline of important moments in the history of **3D printing technology**, from its very first patent to the industry giant it is today.

1980

Hideo Kodama files the first 3D printing patent application, describing a photopolymer rapid prototyping system that uses UV light to harden the material. The idea is never commercialized.

1983

Charles Hull inventes the first stereolithography apparatus (SLA) machine.

1986

Charles Hull is granted the first patent in 3D printing for an SLA machine. Hull goes on to co-found 3D Systems Corporation.

1987

Carl Deckard files a patent for a selective laser sintering (SLS) process. The patent was issued in 1989 to DTM, Inc., a company later acquired by 3D Systems.

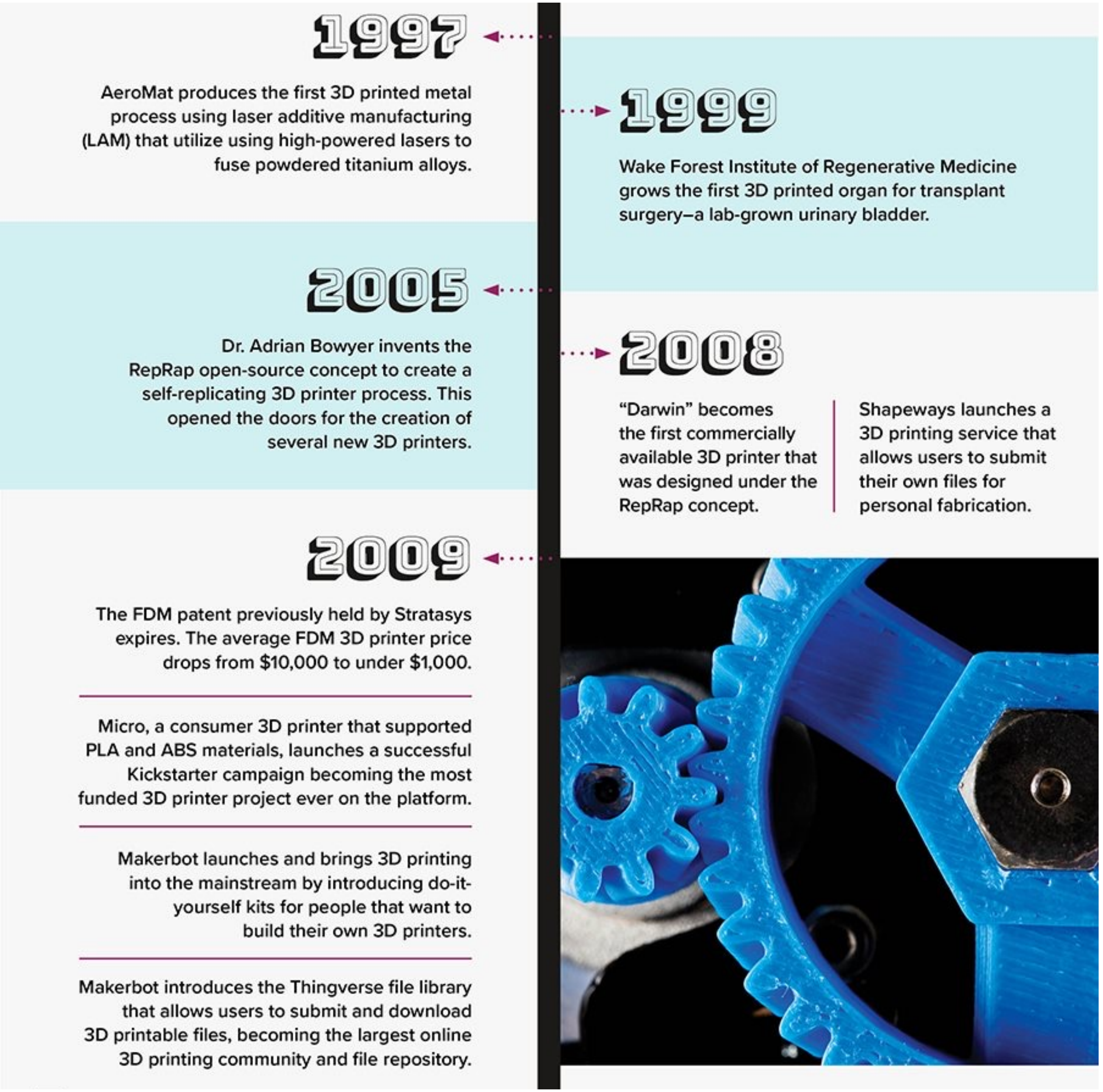
1988

3D Systems sells the first commercial rapid prototyping printer–the "SLA-1".

1989

Scott and Lisa Crump file for a patent for fused deposition modeling (FDM). Scott Crump would go on to co-found Stratasys, Inc.

Hans Langer establishes EOS GmbH in Germany and becomes an industry leader in laser sintering research.



1997

AeroMat produces the first 3D printed metal process using laser additive manufacturing (LAM) that utilize using high-powered lasers to fuse powdered titanium alloys.

1999

Wake Forest Institute of Regenerative Medicine grows the first 3D printed organ for transplant surgery–a lab-grown urinary bladder.

2005

Dr. Adrian Bowyer invents the RepRap open-source concept to create a self-replicating 3D printer process. This opened the doors for the creation of several new 3D printers.

2008

"Darwin" becomes the first commercially available 3D printer that was designed under the RepRap concept.

Shapeways launches a 3D printing service that allows users to submit their own files for personal fabrication.

2009

The FDM patent previously held by Stratasys expires. The average FDM 3D printer price drops from $10,000 to under $1,000.

Micro, a consumer 3D printer that supported PLA and ABS materials, launches a successful Kickstarter campaign becoming the most funded 3D printer project ever on the platform.

Makerbot launches and brings 3D printing into the mainstream by introducing do-it-yourself kits for people that want to build their own 3D printers.

Makerbot introduces the Thingverse file library that allows users to submit and download 3D printable files, becoming the largest online 3D printing community and file repository.

3D printing community and file repository.

2011

In the United Kingdom, the University of Southampton designs and 3D prints the first unmanned 3D printed aircraft.

Kor Ecologic unveils the Urbee, a prototype car with a 3D printed body, at the TEDXWinnipeg conference.

2012

B9Creator and Form 1 launch successful Kickstarter campaigns, introducing into the entry-level market, alternative 3D printing process: DLP technology and stereolithography, respectively.

2013

Stratasys acquires Makerbot for around $400 million.

2015

Cellink, a Swedish company, introduces the first standardized commercial bio-ink to the market, derived from a seaweed material called non-cellulose alginate. The bio-ink can be used for printing tissue cartilage.

Later in the year, Cellink releases the INKREDIBLE 3D printer for bioprinting services, creating an affordable market for bioprinting.

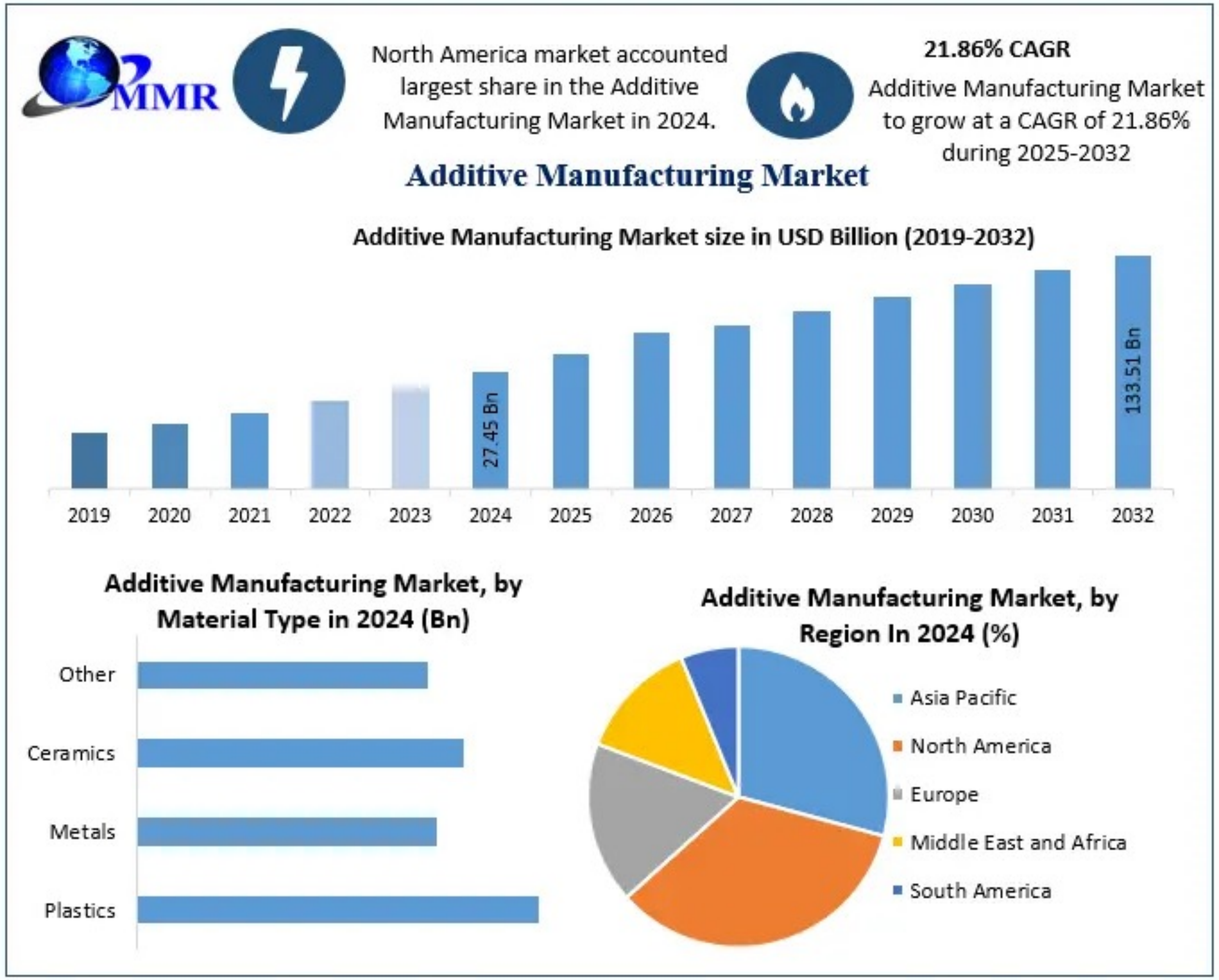
2019

With the expiration of patents and open source projects, there are over 170 3D printer system manufacturers across the world. This list includes: 3D Systems, Stratasys, Fusion3, Formlabs, Desktop Metal, Prusa, and Voxel8, among many others.

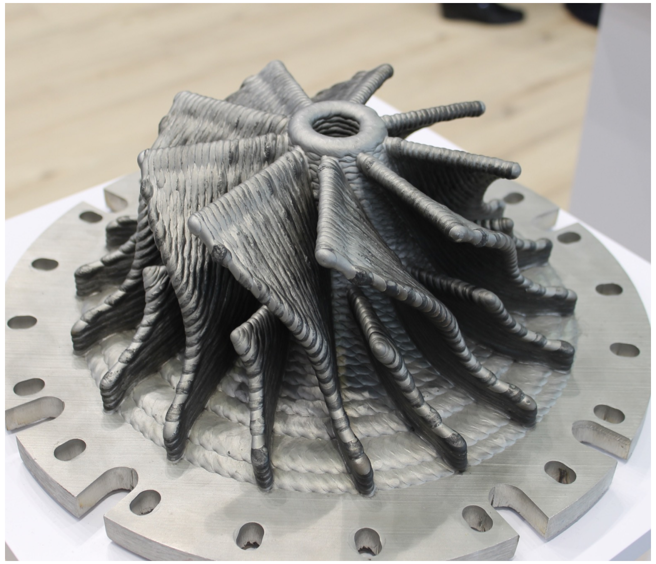
MECHANICAL ENGINEERING
THE MAGAZINE OF ASME

Additive Manufacturing: Projected growth

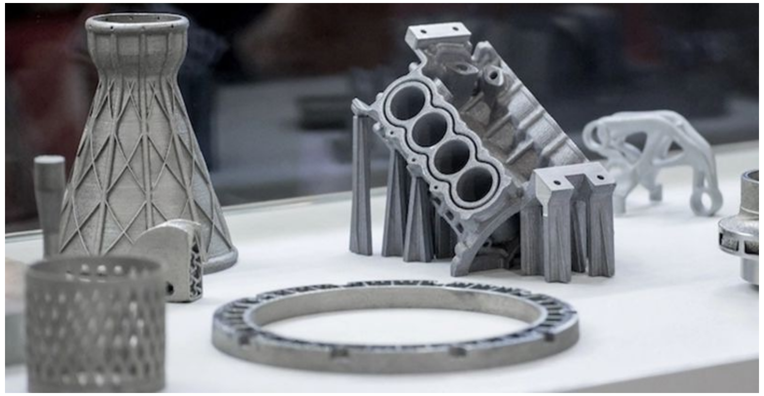
- The wide availability of CAD/CAM software.
- Improved automation and component technologies.
- A growing library of ‘printable’ materials.
- Major industry and government investment.
- Freedom to operate enabled by patent expirations.
- Freedom to explore new design paradigm

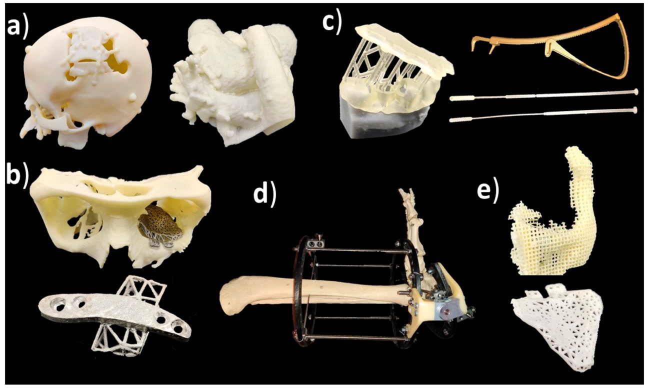


Applications of Additive Manufacturing



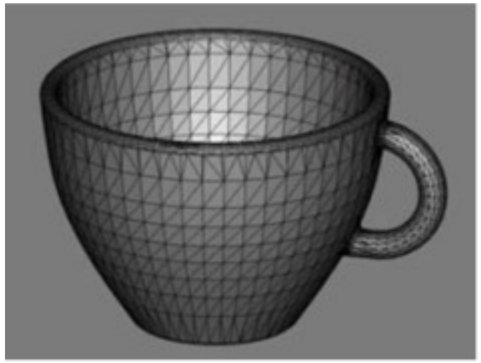
- Aerospace
- Automotive
- Medical (prosthetics, implants)
- Consumer products
- Architecture
- Food





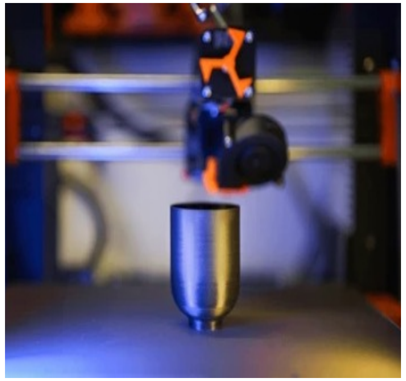
Steps in a typical AM process

1



2

3



4

1 CAD
2 .STL convert
3 Slicing
4 Build
5 Post processing
6 Application

6

5

Materials

Polymers and composites

- Photopolymer
  - Acrylate Resin
  - Bio-based Acrylate
- Thermoplastics
  - Acrylonitrile-Butadiene-Styrene (ABS)
  - Poly-Carbonate (PC)
  - Polylactic Acid (PLA)
- Nylon6 based nano composite
- Carbon fibre reinforced plastic
- Glass fibre reinforced plastic

plastic

Metal

- Titanium alloys
- Nickel alloys
- Aluminium alloys
- Steels
- Copper
- Magnesium

Ceramics

- Phosphate calcium carbonate
- Silica
- Calcium Silicate
- Alumina
- Akermanite
- Ceramic matrix composite

Biomaterials

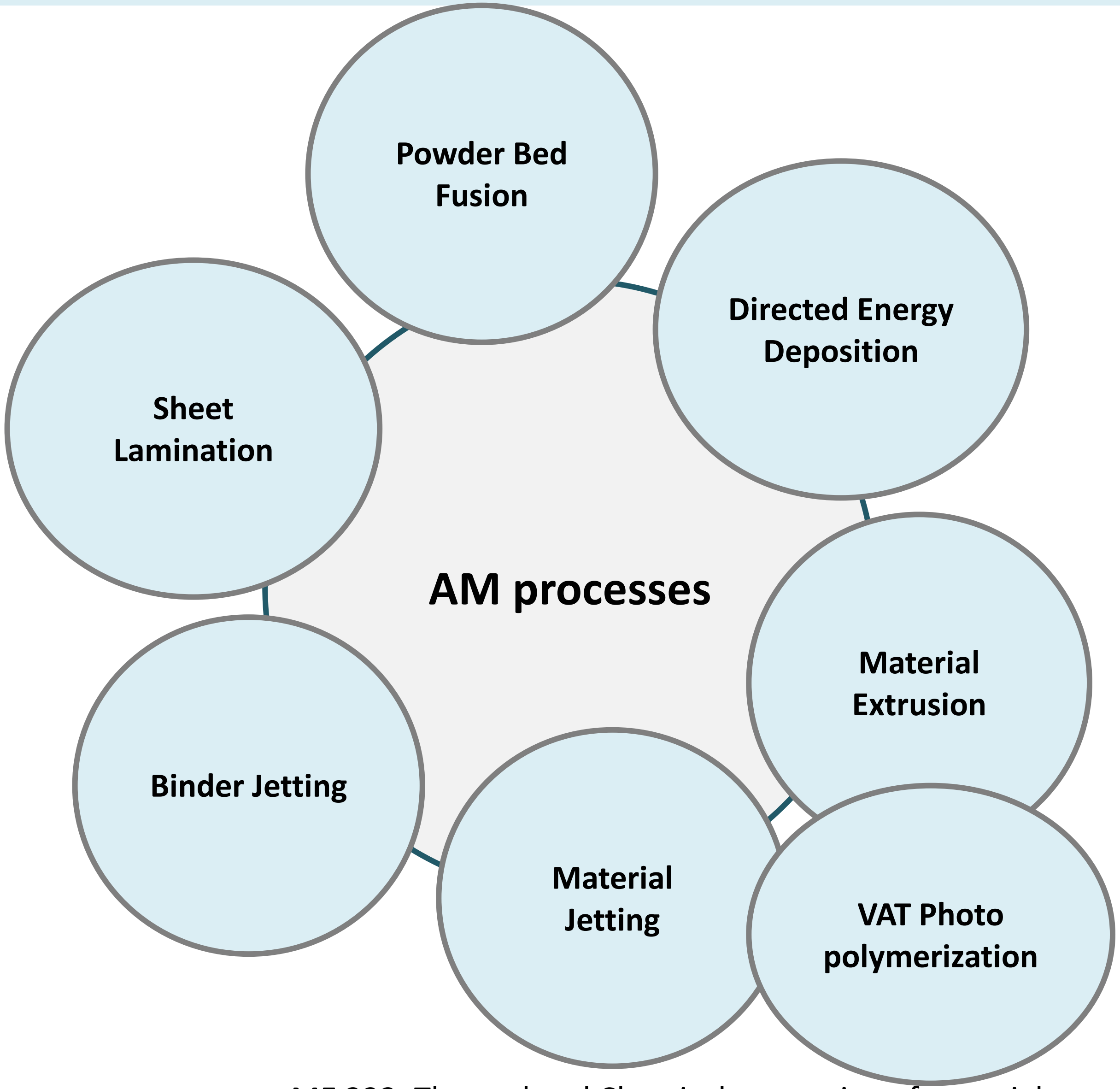
- Bioinks
- Cell laden Hydrogels
- Drugs
- Pharmaceutical material

Construction

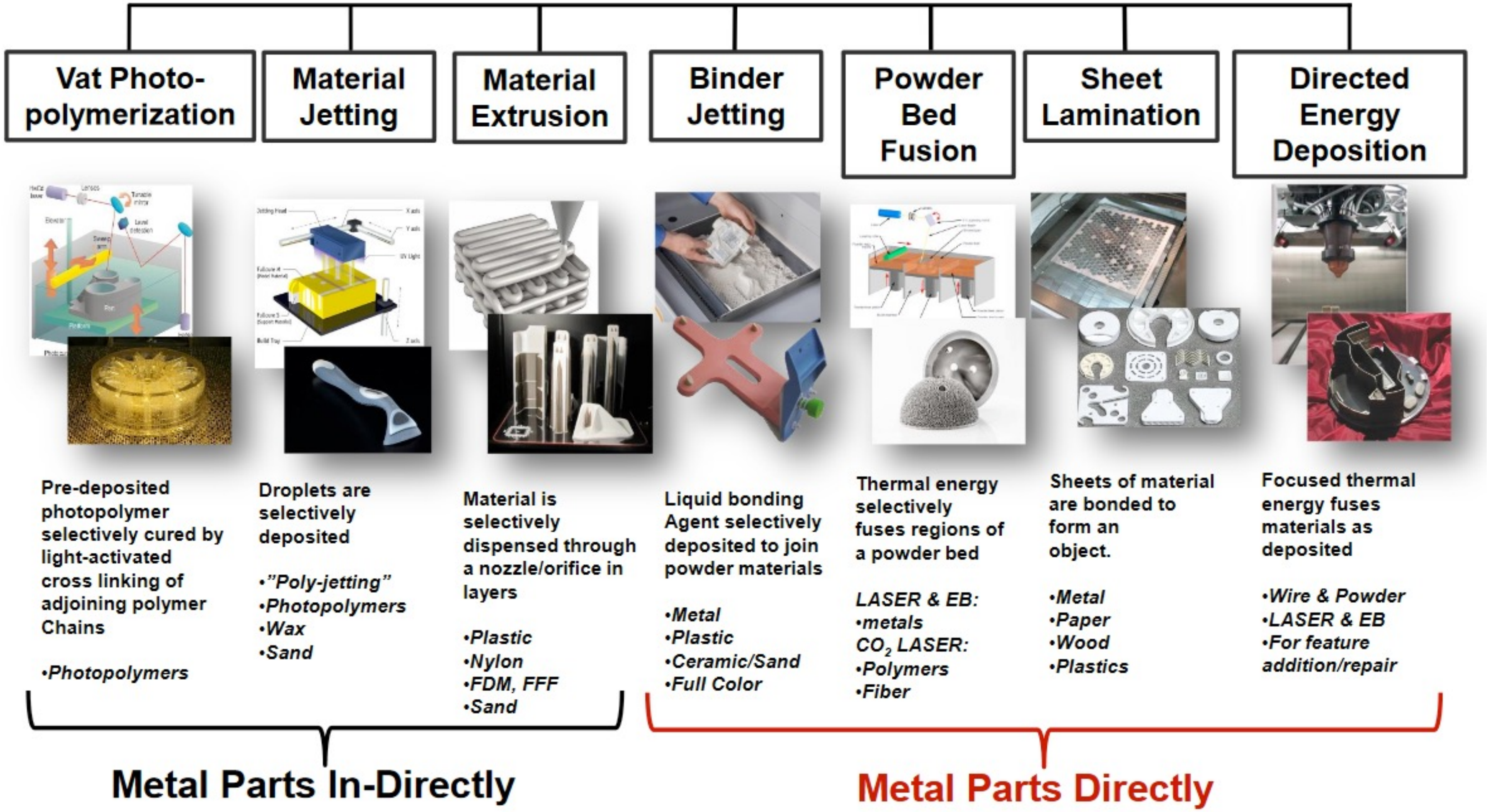
- Cement
- Concrete
- Fiber Reinforced Concrete
- Portland Cement
- Calcium Aluminate
- Polymer Foam

Creation of new alloys metal ceramic composites & FOOD

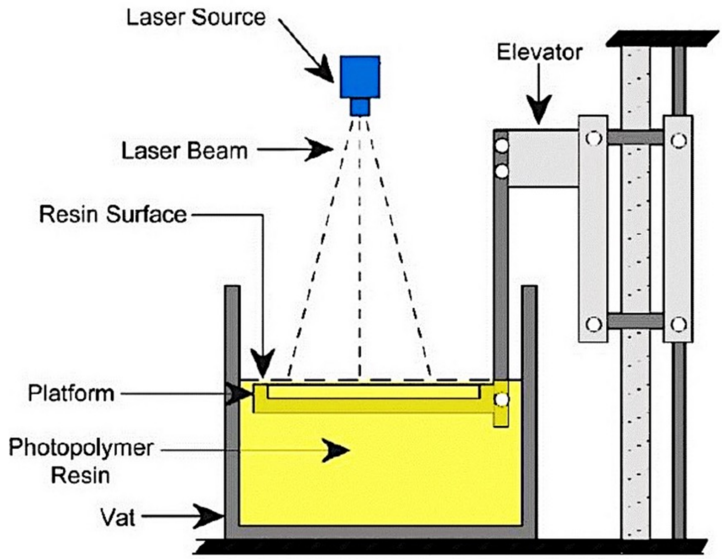
AM Processes and Technologies

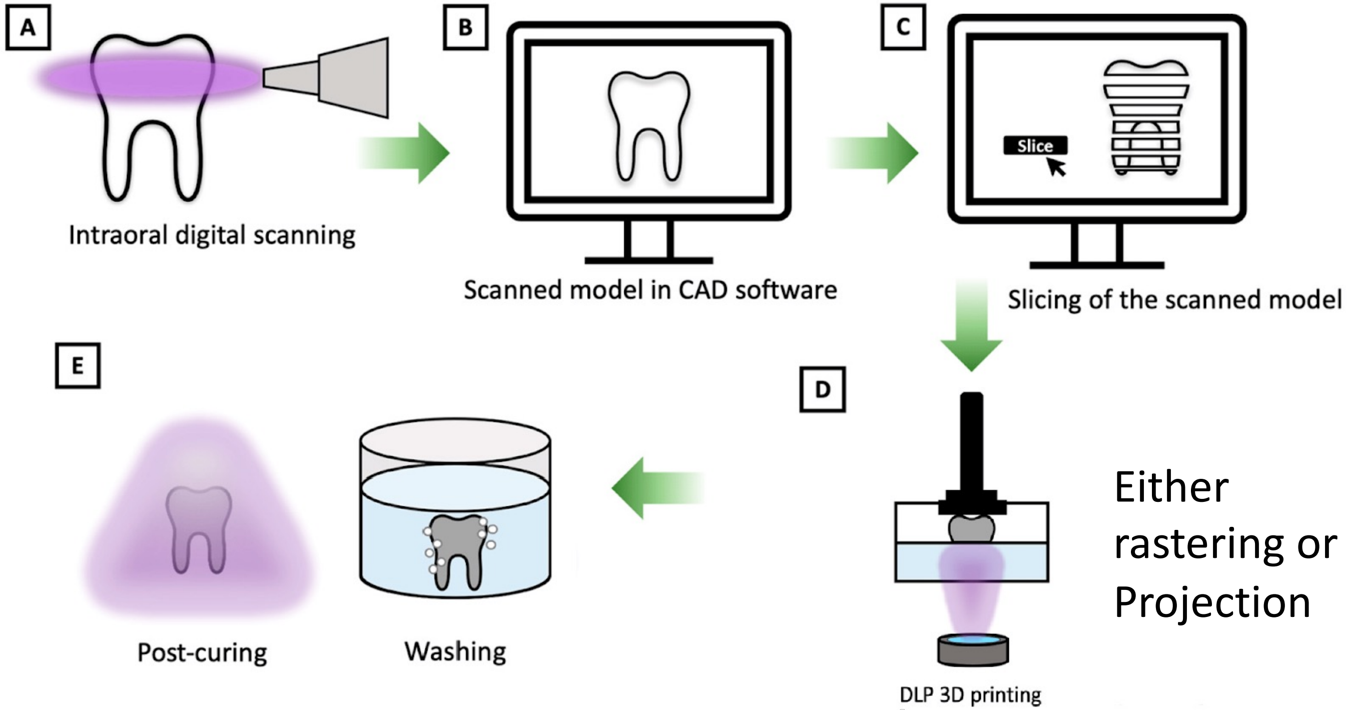


AM Processes and Technologies



Vat Photopolymerization (SLA)

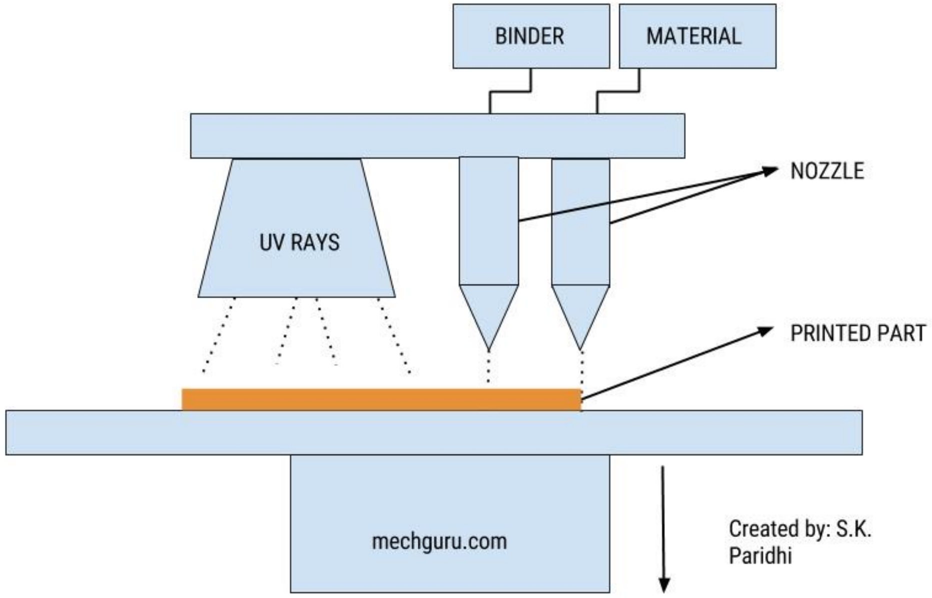


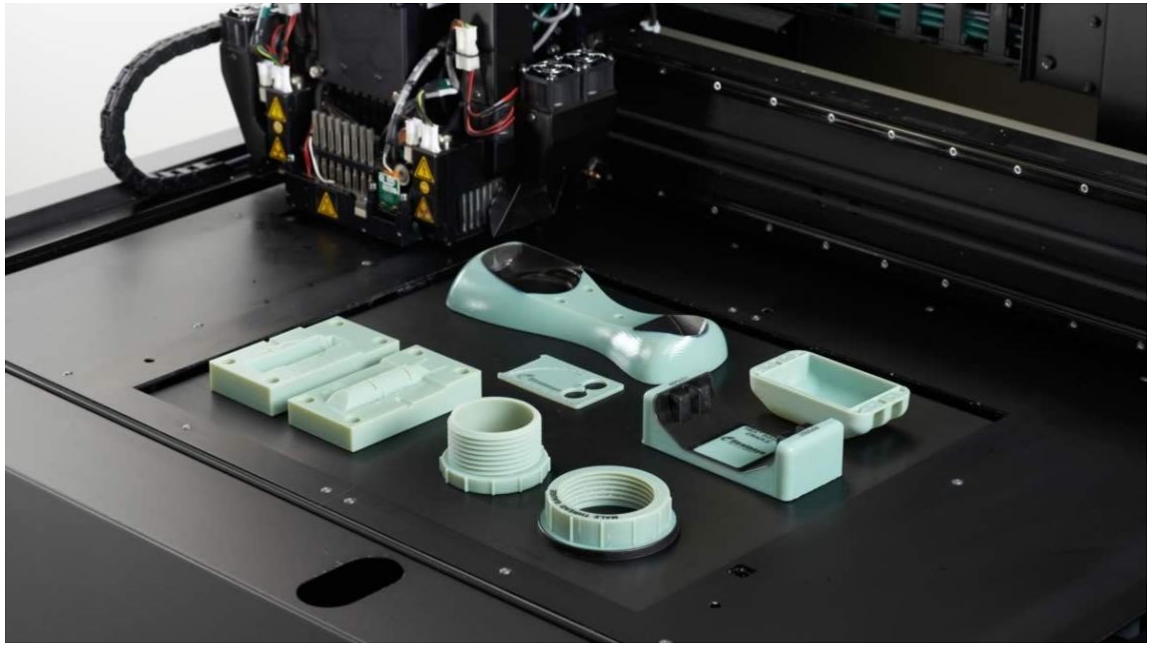


Either rastering or Projection

- Laser beam traces a cross-section of the part pattern on the surface of the liquid resin
- SLA’s elevator platform descends
- A resin-filled blade sweeps cross the section of the part, re-coating it with fresh material
- Immersed in a chemical bath for cleaning
- Stereolithography requires the use of supporting structures

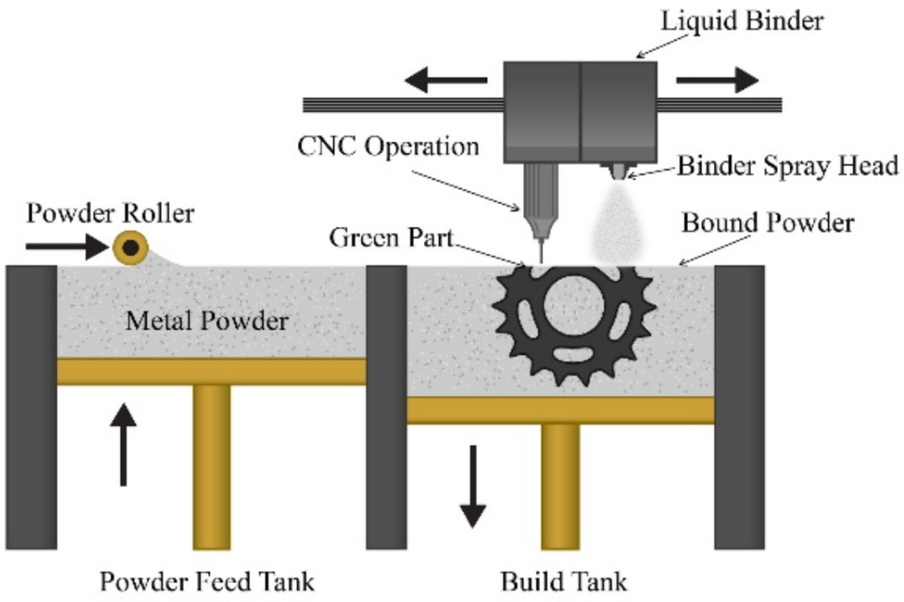
Material Jetting

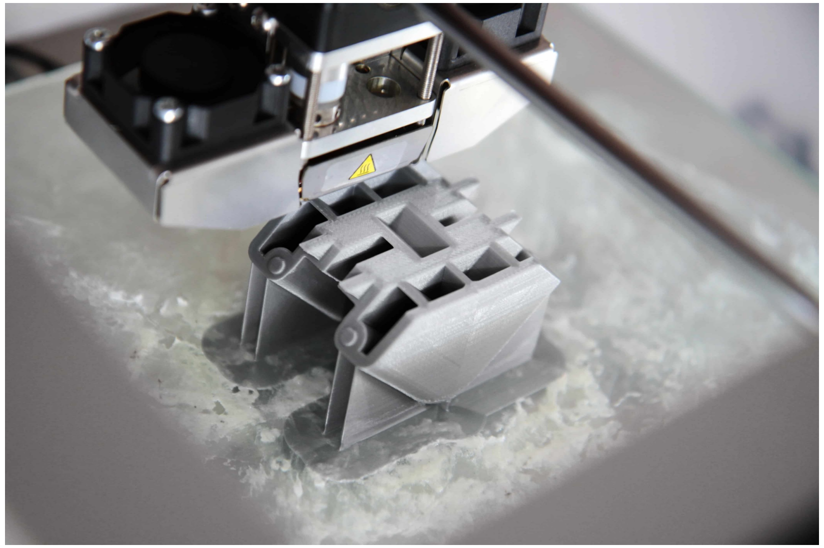




- Drop on demand method
- The print head is positioned above build platform
- Material is deposited from a nozzle which moves horizontally across the build platform
- Material layers are then cured or hardened using ultraviolet (UV) light
- Droplets of material solidify and make up the first layer
- Platform descends
- Good accuracy and surface finishes

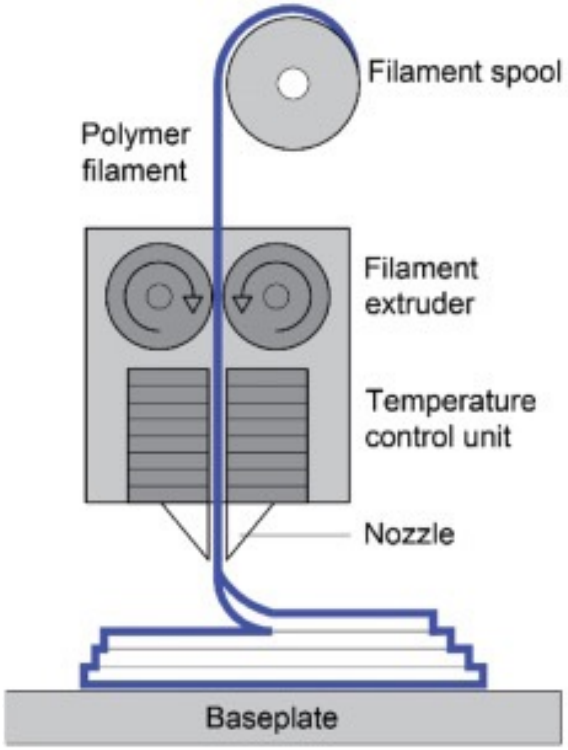
Binder Jetting





- A glue or binder is jetted from an inkjet style print head
- Roller spread a new layer of powder on top of the previous layes
- The subsequent layer by layer is then printed and is stitched to the previous layer the jetter binder
- The remaining lose powder in the bed supports overhanging structure

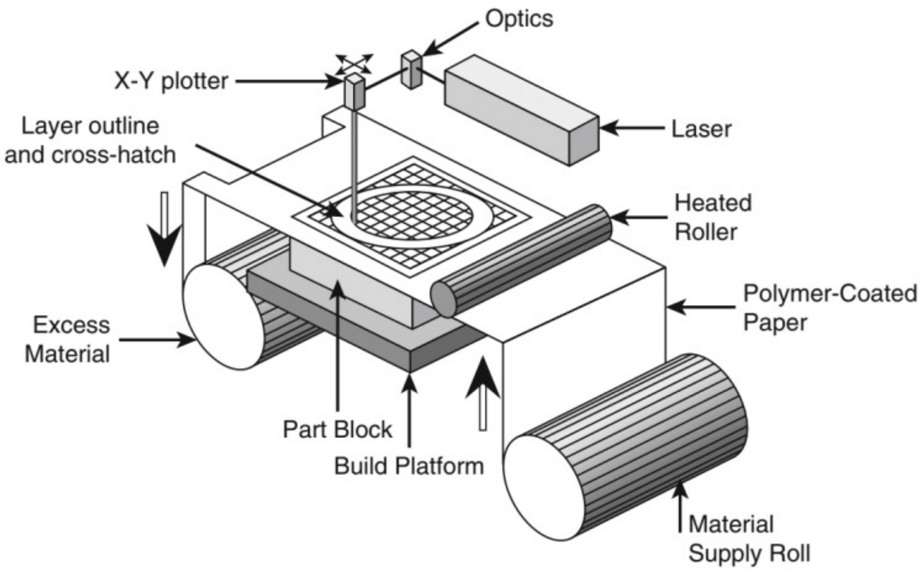
Material Extrusion (FDM/FFF)



FDM 3D printing process

- Fused deposition modelling
- Material is drawn through a nozzle, where it is heated and is then deposited layer by layer
- First layer is built as nozzle deposited material where required onto the cross-sectional area
- The following layers are added on top of previous layer
- Layers are fused together upon deposition as the material is in a melted state

Sheet Lamination

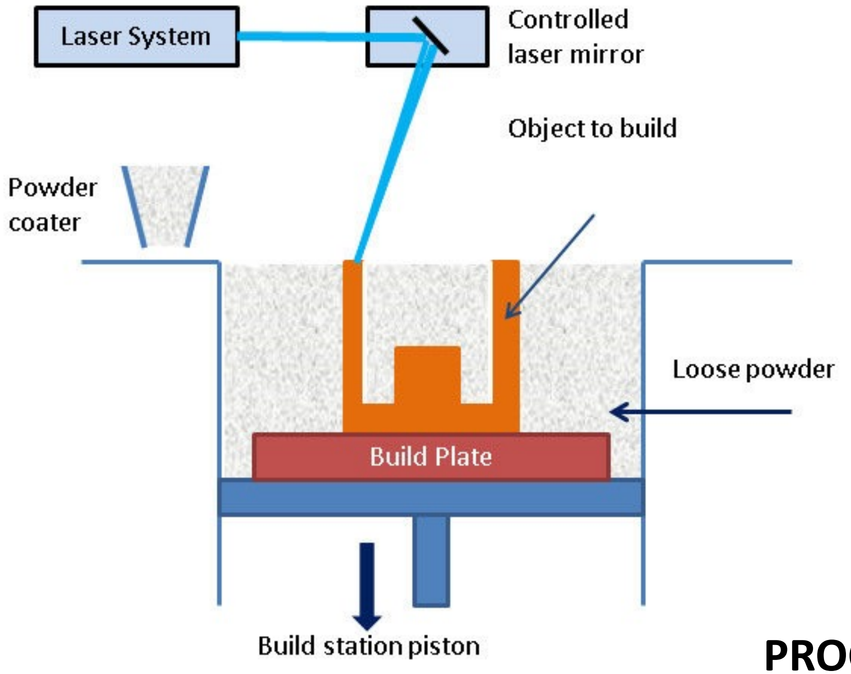


PROCESS

- The material is positioned in place on the cutting bed
- The material is bonded in place, over the previous layer, using the adhesive
- The required shape is then cut from the layer, by laser or knife.
- The next layer is added

- Metal sheets are used
- Laser beam cuts the contour of each
- Glue activated by hot rollers

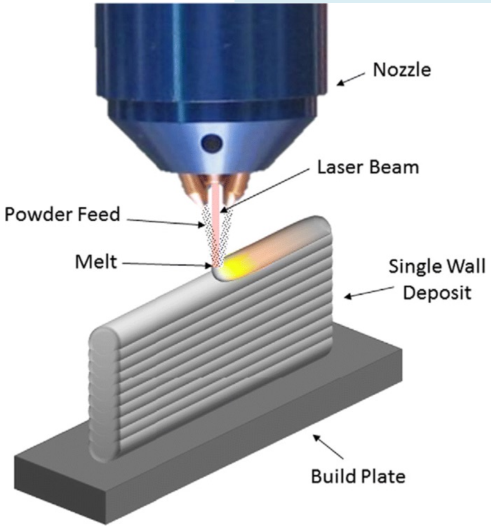
Powder Bed Fusion (SLS, SLM)

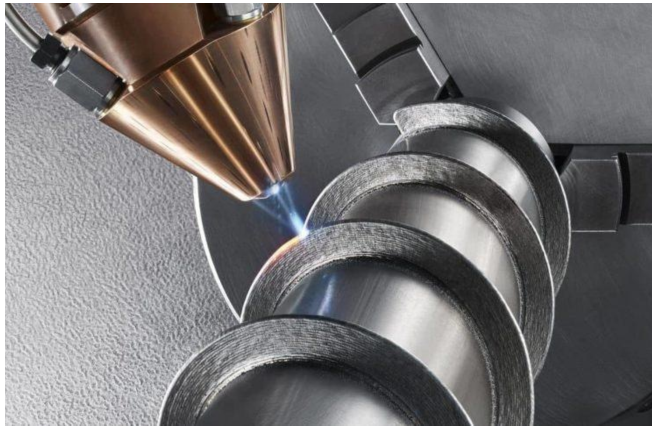


PROCESS

- A layer, typically 0.1 mm thick of material is sprayed over the build platform
- The SLS machine preheats the bulk powder material in the powder bed
- A laser fuses the first layer
- A new layer of powder is spread
- Further layers or cross sections are fused and added
- The process repeats until the entire model is created

Directed Energy Deposition



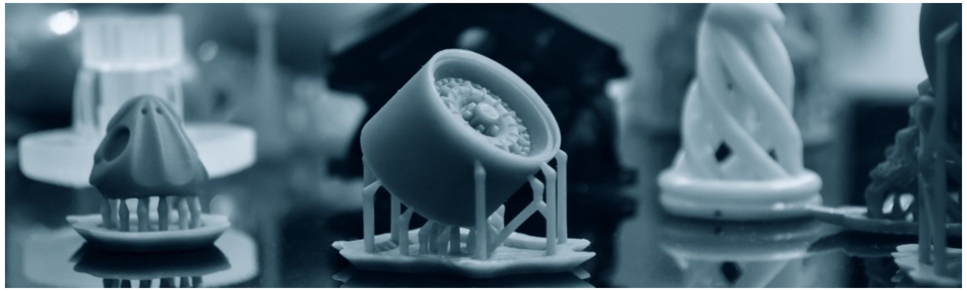


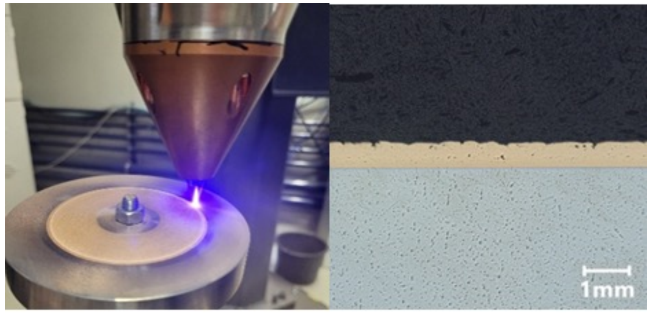
PROCESS

- Consist of a nozzle mounted on a multi axis arm
- Nozzle can move in multiple directions
- Material is melted upon deposition with a laser or electron beam
- A4 or 5 axis arm with nozzle moves around a fixed object.
- Material is deposited from the nozzle onto existing surfaces of the object.
- Material is either provided in wire or powder form.
- Material is melted using a laser, electron beam or plasma arc upon deposition.
- Further material is added layer by layer and solidifies, creating or repairing new material features on the existing object.

Post-Processing Techniques

- Support Removal
- Surface Finishing
- Thermal Treatment
- Machining
- Coating



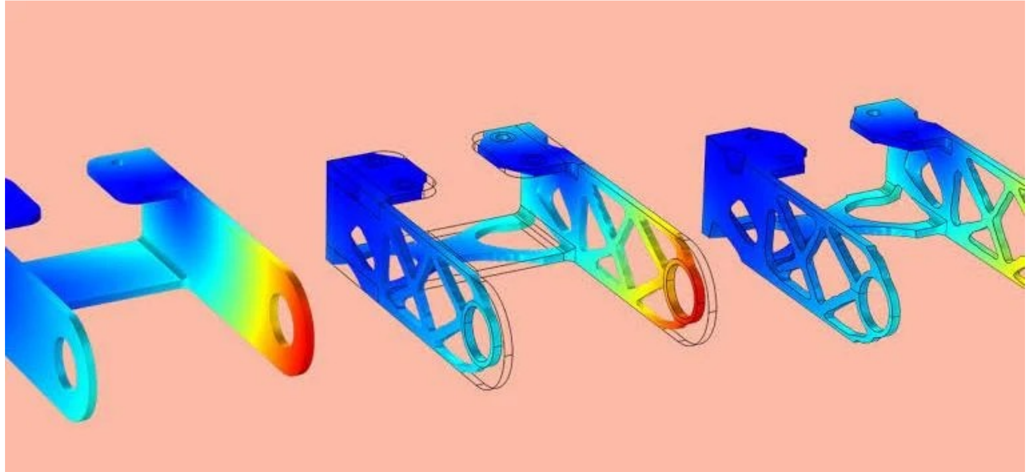


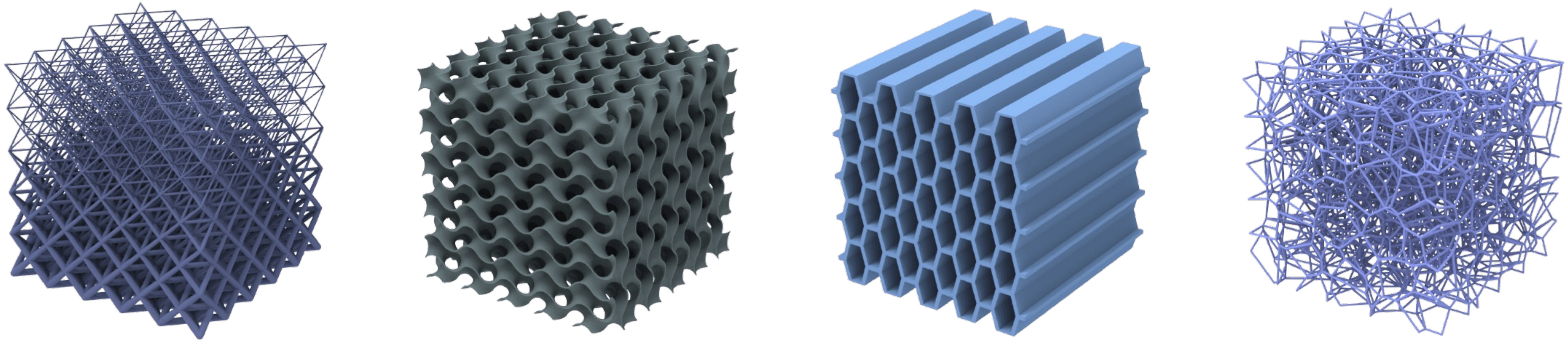
Advantages and Limitations

- Advantages:
  - Customization
  - Low material waste
  - Rapid prototyping
- Limitations:
  - Slow speed
  - Limited materials
  - Poor surface finish

Design for Additive Manufacturing (DfAM)

- Topology Optimization
- Lattice Structures
- Part Consolidation
- Support Structures
- Overhangs and Orientation





Four types of lattice structures; a beam lattice, a TPMS lattice (gyroid), a honeycomb lattice, and a stochastic lattice (Voronoi).

Trends and Innovations

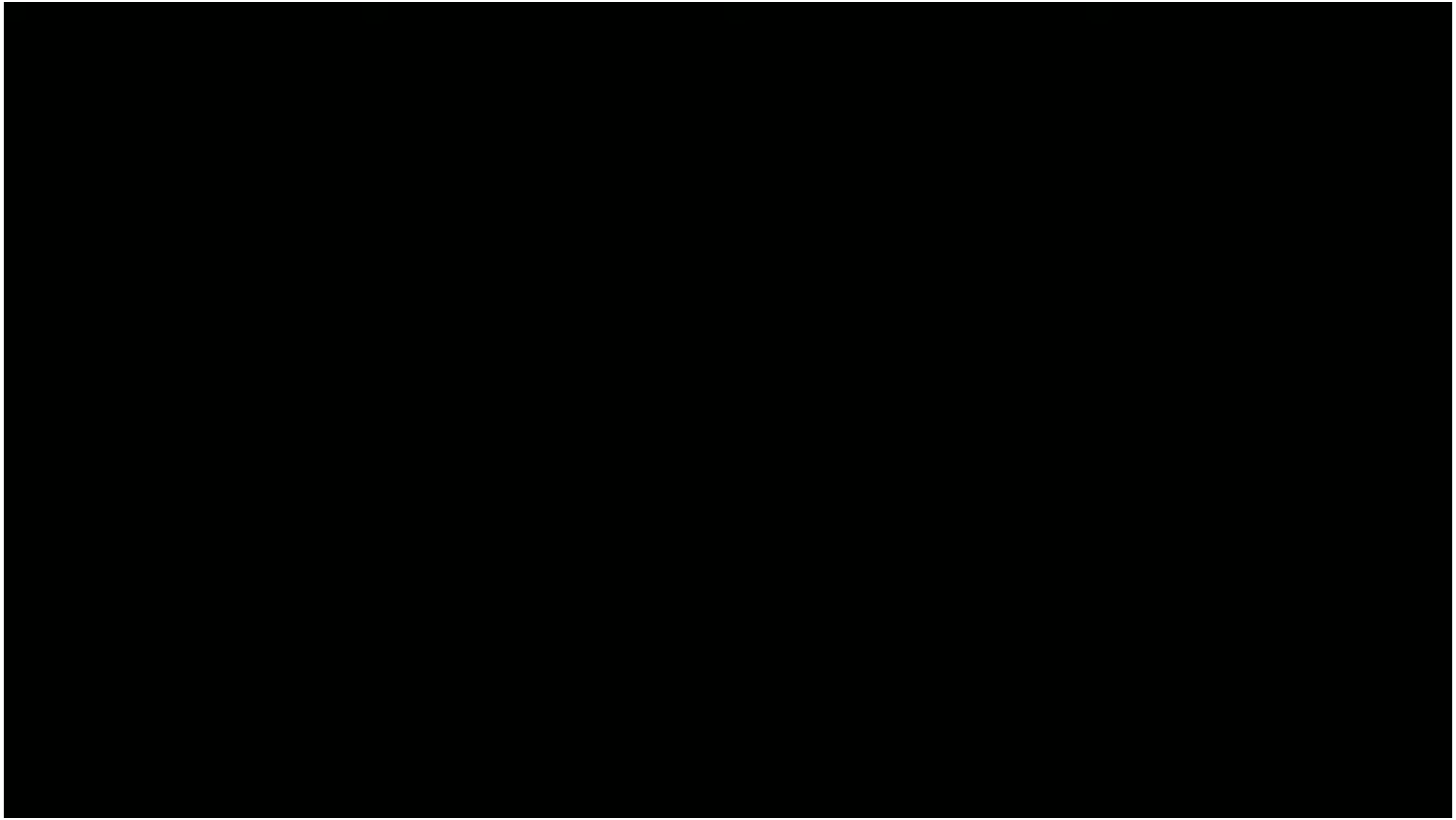
- Multi-material Printing
- 4D Printing
- AI in AM
- Sustainability
- Bioprinting

Case Studies

- GE Aviation – Fuel Nozzle:
  - 25% weight reduction
  - Reduced 20 parts to 1

https://www.youtube.com/watch?v=1L4OFrrq4nQ

3-D Printed Fuel Nozzle



Dental implants Applications

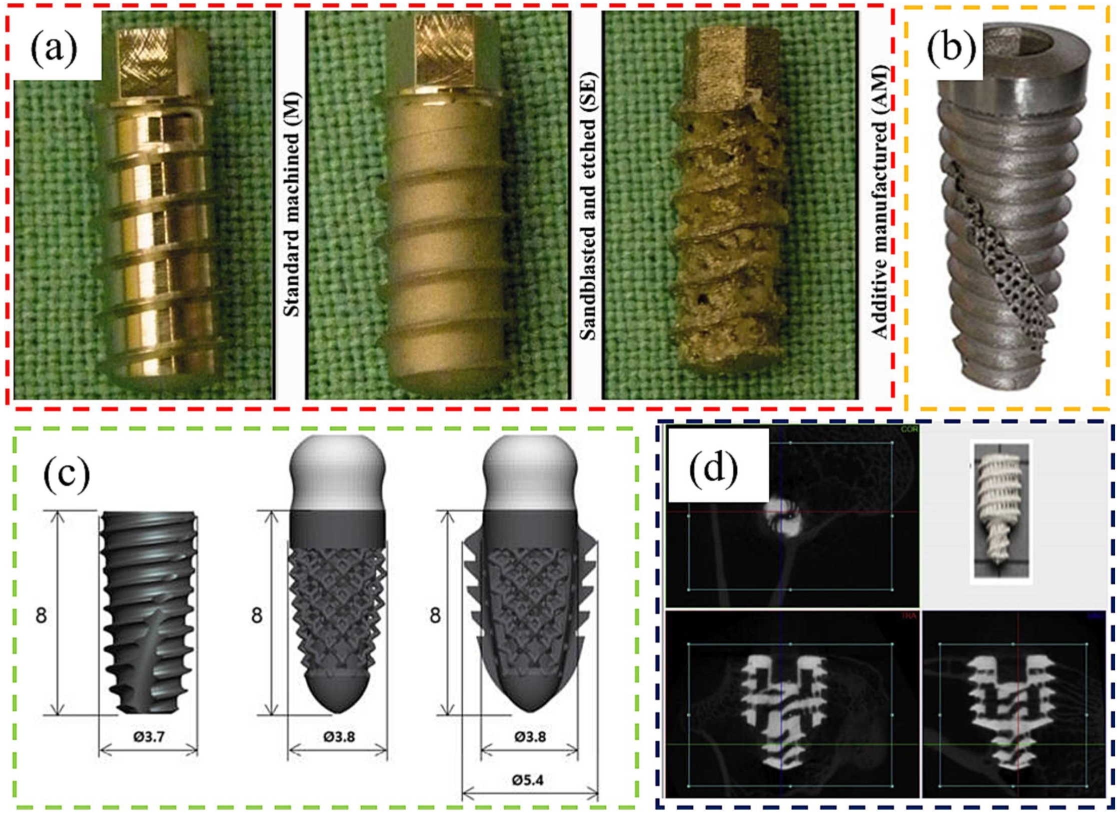


Fig. (a) Titanium alloy porous screws made by DMLS (b) Ti6Al4V porous dental implant made by SLM (c) Ti-Gr2 porous structured dental implants made by SLM (d) Ti6Al4V dental implants made by SLS [Liu et al. (2023)]

https://www.3dnatives.com/en/3d-printing-dental-market-170120184/#!

Standards and Certification

- ASTM F42 – AM standards
- ISO/ASTM 52900 – Terminology
- Quality Assurance in AM
- Part Validation